Chapter 13
Sustainable Forest Management for Mixed-Dipterocarp Forests: A Case Study in Southwest Sri Lanka

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Abstract Mixed dipterocarp forests (MDF) were one of the most timber productive forests in the world. The forest region is named after the dominant canopy tree family Dipterocarpaceae within which two major genera (*Dipterocarpus*, *Shorea*) usually represent a disproportionate amount of the basal area. Compared with Latin America and Africa, MDF have much higher standing volumes of merchantable timber per hectare, but they were also the first to be over exploited and degraded (1970-ongoing). Most are now restricted to upland regions and require various restorative techniques if they are to be successfully managed. This study describes the silviculture of a financially viable management regime for southwest Sri Lanka. Our studies demonstrate that managing MDF for a combination of timber and enrichment plantings of nontimber forest products (NTFP) can be comparable to the most competitive adjacent land use – tea plantations. By managing for NTFP and timber, forest managers have new opportunities to solve the old problems of high-grading and land-use conversion. In addition, payments for ecosystems services that include water quality and yield, and credits for carbon would double forest value when compared with other competing land use values.

Keywords *Calamus zeylanicus* · *Caryota urens* · Cardamom · Dipterocarps · *Elettaria cardamomum* var. *major* · Enrichment planting · Light-hardwoods · Nontimber forest products · Rattan · Silviculture · *Shorea* spp.

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13.1 Introduction

Mixed dipterocarp forests (MDF) can be defined by the intimate mixtures of canopy trees, all in the family Dipterocarpaceae, that dominate the late-successional rain-forest within the aseasonal wet tropics of Asia (Malaysia, Sumatra, Kalimantan, southwest Sri Lanka, and parts of the Philippines and Greater Celebes) (Appanah 1998). The tree family Dipterocarpaceae comprise 15–19 genera and 470–580 species (depending on differing taxonomic interpretations – Maury-Lechon and Curtet 1998). By far the majority of the genera and species are in Asia, with some species in Africa, and several in South America. Well-known genera within the family are *Dipterocarpus*, *Dryobalanops*, *Hopea*, *Shorea*, and *Vateria*. Many provide timber under various market names (e.g., luan, meranti, seraya, Philippine mahogany), making the mixed-dipterocarp forest region the largest exporter of hardwood timber on world markets during the major period of their exploitation (1965–1995).

The climate of mixed-dipterocarp forests can be considered perhumid with rainfall usually exceeding 3,000 mm year^{-1}, and mean annual temperatures of about 25°C with greater diurnal variations (±5°C) than seasonal and with annual dry seasons not usually exceeding 3 months. Soils comprise weathered in-situ Ultisols (red-brown earths) or less commonly Oxisols (latosols) (USDA 1975), which would be considered relatively infertile when compared with the volcanically derived soils of Central America, but comparable or slightly more fertile to the weathered Oxisols of Central Africa and the lower Amazonian terra firme region of South America.

Mixed-dipterocarp forests can be divided coarsely into lowland and hill forest types. Lowland forests are those below 200 m asl, usually restricted to the coastal plains and to areas not subject to flooding or inundation. Hill forests are restricted to elevations between 200 and 1,000 m asl and make up the foothills of the central mountain ranges of Borneo, Sumatra, Sri Lanka, the Philippines, and peninsula Malaya. After logging, many of the more accessible lowland forests were cleared for permanent agriculture and plantations (rubber, tea, oil palm). The remaining dipterocarp forests are now mostly restricted to the hill and mountain forests. Most have been logged over and are in poor condition.

In this study, we describe the ecology and protocols for sustainable management of hill mixed dipterocarp forest of southwest Sri Lanka. We believe it is one of only a few tropical forest examples of a silvicultural system that has been grounded on the ecological science of the forest with demonstrated financial sustainability. The management described in this study is based on 30 years of studies investigating the regeneration ecology, breeding biology, phenology, silviculture, and economics of trees, lianas, and shrub species that provide products and services for local and regional markets.

13.2 The Case Study Site Description

The greater region of Sinharaja (an MAB reserve and World Heritage Site) and surrounding forest reserves comprises about 50,000 ha, and is located in hill mixed dipterocarp forest in the ever-wet south-western region of Sri Lanka (6°21–26′N, 80°21–34′E). In Sri Lanka, the forest has been classified as a Mesua-Shorea community (De Rosayro 1942). The floristics has been well described (Gunatilleke and Gunatilleke 1981, 1983, 1985; Ashton et al. 2001a).

The forest largely comprises ridge-valley topography (200–300 m elevation difference) aligned northeast–southwest, with spurs and drainages that run across the slopes. The topography generally increases in elevation from the southwest toward the northeast from 200 to 1,000 m asl (Fig. 13.1). Seepage ways and many perennial streams cut across these slopes and run along the valleys. This landform is a result of differential weathering and erosion of less-resistant Precambrian metamorphic bedrock along structurally controlled parallel strike ridges and valleys (Cooray 1984; Erb 1984). The region receives 4,000–6,000 mm of rainfall per year. Most rain falls during the southwest (May–July) and northeast monsoons (October–January). Seasonal temperatures range between 25 and 27°C with a greater diurnal variation of (±4°C). Soils are classified as ultisols following the USDA (1975) terminology, or red-yellow latosols, using the classification system of the Food and Agriculture Organization (Moorman and Panabokke 1961).

13.3 Ecology of the Forest

To summarize the dynamics of the forest type, seven ecological principles can be considered. First, natural regeneration of mixed dipterocarp forest ultimately arises after many kinds of disturbance that are nonlethal; with late-seral canopy tree species occupying growing space before a disturbance, pioneers establishing immediately after a disturbance, and most shrubs and small treelets reproducing vegetatively. The process promotes the simultaneous initiation of pioneers and release of existing advance regeneration, and sprout growth into a new stand that is termed allogenic (initial floristics) – meaning that *all regeneration starts together* (Oliver and Larson 1996).

Second, all the tree species that dominate the canopy late seral-stages of forest development are dependent upon existing in the understory as advance regeneration. Disturbance regimes are therefore largely nonlethal to the vegetation in the understory.

Third, advance regeneration usually grows for at least a period of time beneath the intact canopy and so has to tolerate high amounts of shade (i.e., 0.5–1.0% of full sun – Ashton 1992a) and competition from understory shrubs. Advance regeneration species differ in shade tolerance, therefore promoting differing degrees of survival (Ashton and Berlyn 1992; Ashton 1995; Ashton et al. 1995; Gamage

Fig. 13.1 Location map illustrating remaining mixed dipterocarp forest in southwest Sri Lanka. The study site is depicted by the S and *arrow*. Alignment is north–south. Scale 1 cm to 15 km

et al. 2003; Singhakumara et al. 2003; Ashton et al. 2006). For example, *Shorea trapezifolia* has frequent masting events with low survival in understories (90% of a cohort is dead after 2 years), whereas *S. worthingtoni* has infrequent masting events once in every 5–7 y with high survival (50% of a cohort survives 20 years after germination) (Ashton et al. 1995). However, all species maintain the same capacity to initiate rapid height growth whenever a canopy disturbance releases them (Ashton et al. 1995).

Fourth, natural disturbances are not uniform in severity, type, and extent but change in relation to topographic position. In southwest Sri Lanka, trees on ridge sites and thin to bedrock slopes are susceptible to drought effects, particularly during El Nino years (1983; 1991–1992; 1997–1998), and also to lightning strikes. Mid slopes are prone to landslides, particularly with the onset of monsoons; differences in aspect also make exposed slopes prone to multiple tree falls and monsoon downbursts than more sheltered slopes (Ediriweera et al. 2008). Areas with streams and rivers that are seasonally flooded have trees with shallow roots that are prone to wind throws from sudden downdrafts channeled into valleys (Ashton 1992a; Ediriweera et al. 2008).

Fifth, tree species can be grouped into six broadly defined guilds based on ecological similarity of regeneration origin (advance regeneration, vegetative sprout, buried seed, and/or seed that colonizes after a disturbance), stage of stand development (stand initiation, stem exclusion, understory reinitiation – after Oliver and Larson 1996), and growth habit (understory, subcanopy, canopy). The six guilds and their approximate species numbers are as follows: (1) pioneers that dominate stand initiation (animal dispersed postdisturbance or buried seed banks; 10–20 spp.); (2) pioneers that dominate stand stem exclusion (wind or animal dispersed postdisturbance; 15–25 spp.); (3) late-successional canopy dominants (advance regeneration; masting; 55–75 spp.); (4) late-successional canopy nondominants (advance regeneration – density dependent; 15–25 spp.); (5) late-successional subcanopy (advance regeneration – density dependent; vegetative sprout; 35–45 spp.); and (6) late-successional understory (vegetative sprout; 60–80 spp.). The majority of guilds clearly represent regeneration that exist prior to disturbance ("advance" regeneration, vegetative sprout) for representation in the new stand (Ashton 1992b).

Sixth, two forest canopy stratification processes can contribute to the dynamics of mixed-dipterocarp forests (Ashton and Peters 1999). The first process includes those long-lived species that occupy different vertical strata within a mature forest stand. We have referred to this kind of stratification at the mature phase of stand development as "static stratification," with understory species representing smaller (as defined by their diameter and height class distribution) and more numerous individuals than the true canopy trees species. In a combined way, they represent the four late-successional regeneration guilds of the six described earlier (canopy dominant, canopy nondominant, subcanopy, and understory). The second forest canopy stratification process involves species of different stand developmental (successional) status that sequentially gain dominance of the canopy. We have defined this as "dynamic stratification." In this forest, *Macaranga peltata* (pioneer of initiation phase) attains the canopy of the mixture early in stand development, but this position is usurped first by *Alstonia scholaris* (pioneer of stem exclusion phase) and then by *S. trapezifolia* (late-successional canopy dominant). Both stratification processes occur over the course of stand development following initiation, stem exclusion, understory initiation, and old growth phases as described by Oliver and Larson (1996) (Fig. 13.2a, b).

Seventh and last, most of the late-successional canopy dominants of the forest (that often exhibit masting) are restricted to particular topographic positions within the landscape (Fig. 13.3a–d). Species differentiate in relation to frequency and type of disturbance, and differences in soil-water availability and soil nutrition (Ashton 1995; Ashton et al. 1995, 2006; Gunatilleke et al. 1997, 1998, 1996). Most late-successional canopy nondominant species are usually site generalists (see Fig. 13.3e, f), though they represent fewer numbers of species than canopy dominants. Late-successional site generalists in this forest type are usually dependent upon medium to large-sized animals (bat, bird, civet, primate) for effective long-distance seed dispersal. Many of the site generalist species exhibit density dependence (e.g., seedlings do not do well near parent trees because of proneness to herbivory,

Fig. 13.2 (**a**) A simplified diameter distribution for a mature mid slope mixed dipterocarp forest depicting: *Shorea trapezifolia* (A – late-successional dominant canopy emergent); *Garcinia hermoni* (B – late-successional subcanopy tree); *Humboltia laurifolia* (C – late-succesional understory tree); and *Agrostistachys hookeri* (D – late-successional understory shrub). (**b**) A vertical photographic profile illustrating "Static canopy stratification" for the same mixed dipterocarp forest as illustrated by the adjacent diameter distribution. (**c**) A simplified illustration of the hypothetical change in diameter distributions for tree species that attain the canopy at early, middle, and late-stages of stand development in "dynamic canopy stratification" of a mixed dipterocarp forest (1 – stem exclusion stage 15-years; 2 – stem exclusion stage at about

pathogens, insects). Site-restricted species are usually dispersed only a limited distance from parent trees by small territorial animals (rodents) or gravity (aided by wind).

Silvicultural prescriptions for regeneration methods in this forest type must cater to all regeneration guilds to maintain floristic diversity (Ashton 1992b, 1998). However, the late-successional canopy dominants (dipterocarps in particular) form the structural complexity of the mature phase. Given their masting phenology, restricted distributions, and reliance upon advance regeneration, prescriptions are focused on emulating disturbances that promote their establishment and release. Such prescriptions need to be site specific to topographic position, soil type, and elevation to cater to their differing shade tolerances and edaphic specialization (Ediriweera et al. 2008). The core structure of the forest type is therefore an assemblage of species associations unique to different parts of the landscape – making for a complex forest mosaic (Ashton 1998). In this forest type this is the base building block upon which to develop silvicultural treatments.

13.4 The Forest Condition and Floristic Associations

13.4.1 Dynamics of Undisturbed Forest

Let us now go further into the specifics of the ecological principles described earlier for the purposes of applying sound ecologically based silviculture. Three main floristic associations for silvicultural application can be categorized for the study region and can be defined by topographic position – valley, midslope, and ridge (Ashton and Peters 1999). This is a practical simplification of the eight ecological habitats derived from aspect (2) and topographic position (4) (Gunatilleke et al. 2004, 2006).

The three floristic associations can be broadly defined by the site-restricted late-successional canopy dominant tree species. For example, valley associations are composed of *Dipterocarpus hispidus*, *Shorea megistophylla*, and *Mesua ferrea*. Midslope sites are represented by *S. trapezifolia*, *Shorea disticha*, and *Syzygium rubicundum*. The ridge association is composed of *S. worthingtonii* and *Mesua nagassarium* (Ashton and Peters 1999; Gunatilleke et al. 2006).

Fig. 13.2 (continued) 45 years; 3 – understory initiation stage at about 80 years). (**d**) Dynamic canopy stratification depicted in the vertical photographic profile of a 15-year-old mixed dipterocarp stand in the stem exclusion stage, Sinharaja forest. The photograph provides a snapshot of an early phase of stand development on a valley site with the pioneer of stand initiation *Macaranga peltata* (A) in the canopy, the pioneer of stem exclusion *Schumacheria castaneifolia* (B) in the subcanopy, and the late-successional canopy dominant *S. megistophylla* (C) in lower subcanopy. Species representative of truly below-canopy growth habits (those that comprise the different "static" below-canopy strata in a mature stand) are also present in the understory of this photograph (modified after Ashton et al. 2001a)

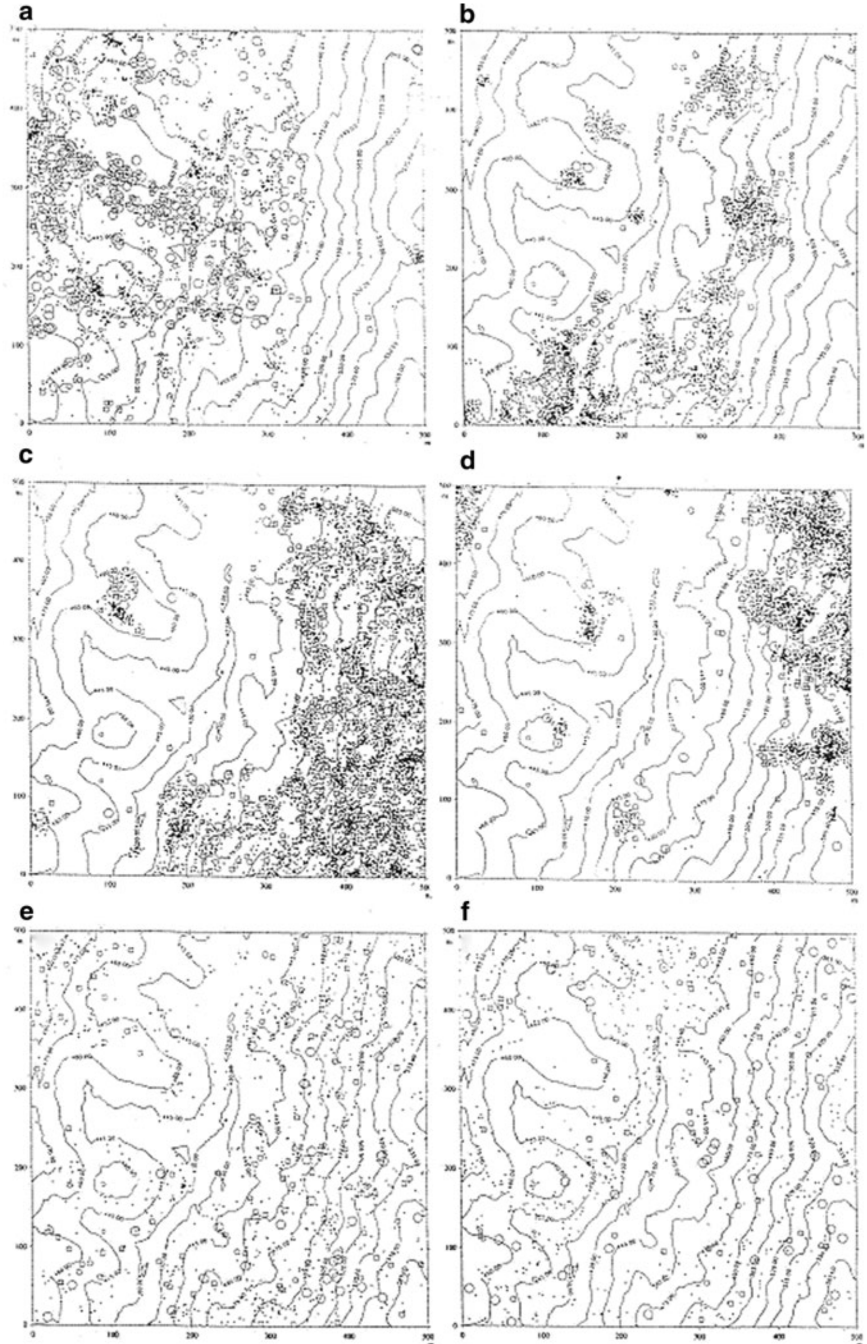

Fig. 13.3 Shows examples of site-restricted and site-generalist tree species distributions across the ridge-valley topography of the Sinharaja forest. Stem maps for each of six dominant tree species with the same 25 ha plot of mature mixed dipterocarp forest; all stems >2 cm dbh of each species have been depicted separately in each stem map. The *contour lines* over each map are at

13.4.1.1 Comparisons Between Valley, Mid Slope, and Ridge Associations

During high rain events (monsoons), the valley association endures seasonal high water tables forcing trees to have shallow rooting systems. This periodic water-logging process, in combination with downdrafts from convectional windstorms channeled through valleys, results in multiple tree falls (Ashton et al. 2001a). Rain-soaked soils from monsoonal events make the midslope association prone to earth slips and landslides.

In the valley association, soils are therefore wetter and average understory conditions have higher amounts of light with much greater degrees of variability (mean PPFD 1 mol m^{-2} day^{-1}, ±1 SD) when compared upslope with midslope and ridge associations (mean PPFD 0.5 mol m^{-2} day^{-1}, ±0.25 SD). This is because the valley association has the following: (1) an intermittent but tall stature canopy (55 m) that promotes greater light reflection and diffusion; (2) larger canopy gaps and the edge effects that they create; and (3) more frequent multiple wind throws especially along streams and rivers when compared with the ridge association (Ediriweera et al. 2008).

Compared with the valley association, the ridge association has soils that are shallow, more prone to desiccation, a shorter canopy tree stature (25 m), and under-stories that receive lower amounts of light (Ashton 1995; Ashton and Berlyn 1992; Ashton et al. 1995; Burslem et al. 2001). Because the ridge association is susceptible to water shortage, particularly during El Niño years, and also to lightning strikes (Ashton et al. 2001a, b), the gaps created by these events are smaller with trees that die standing creating minimal soil disturbance.

The valley association has the lowest density of individuals ≥1 cm DFH (>2,000 ha^{-1}), whereas the ridges have the highest densities (>10,000 ha^{-1}; Gunatilleke et al. 2006). Mean basal area among associations ranged from 30.5 m^2 ha^{-1} in valleys, to 60 m^2 ha^{-1} on ridges. However, the greatest number of larger diameter trees (>50 cm DBH) are on the lower slopes and valleys, but they are still relatively few in number compared with the number of canopy trees on the ridge association (Gunatilleke et al. 2006). Canopy crown densities increase and canopy crown size decrease from valley association to ridge association, driven by the water

Fig. 13.3 (continued) 15 m intervals. The *circles*, *squares* and *dots* depict the stems of a species. For this composite figure it is important to note the general distribution of stems for a given species rather than the nature of whether it is a *circle* (big tree), *square* (medium sized tree) or *dot* (sapling). Species have been divided as follows (1) four late-successional canopy tree dominant species that have restricted site distributions **(a)** *Shorea trapezifolia* – distributed across mid-slopes with a southeastern aspect; **(b)** *Shorea disticha* – distributed across mid-slopes with northwestern aspects; **(c)** *S. megistophylla* – distributed along the toes of slopes and seepages with northwestern aspects; **(d)** *S. worthingtonii* – restricted to the ridges and knolls of slopes primarily with a northwestern aspect; and (2) two late-successional nondominant canopy trees considered to have general distribution (e) *Mangifera zeylanica*; and (f) *Bhesa ceylanica* (modified after Ashton et al. 2001a)

relations of the slope (Ediriweera et al. 2008). Forest canopies are therefore more compact and uniform on the ridge than in the valley (Ediriweera et al. 2008).

Faster-growing more shade intolerant canopy dominant tree species (e.g., *D. hispidus*, *S. megistophylla*, *S. trapezifolia*, *S. rubicundum*) establish more successfully in these lower-elevation valley and mid slope sites (Ashton et al. 1995; Ashton et al. 2006). The three most abundant species $\geq$1 cm dbh in the valley association are the shrub species *Psychotria nigra*, *Urophyllum ellipticum*, and *Schumacheria castaneifolia*, with densities of 240, 160, and 142 individuals ha^{-1}.

On ridge sites, the three most abundant species found are a canopy tree, *M. nagassarium*, a treelet, *Agrostistachys intramarginalis*, and an understory tree, *Humboldtia laurifolia*, which comprised exceptionally high densities of 552, 752, and 978 individual ha^{-1}, respectively (Gunatilleke et al. 2006). *Shorea worthngtonii* and *M. nagassarium* are shade-tolerant and slow-growing species adapted to regenerate in such conditions (Ashton et al. 1995, 2006).

13.4.1.2 Trends in Diversity Across Topography

In the Sinharaja region, topographic and edaphic specializations play a significant role in the spatial distribution of species. Intermediate disturbance conditions may contribute to higher species richness and diversity in the more disturbance prone valley association (78 spp. ha^{-1}) than on the more stable conditions of the ridge association (55 spp. ha^{-1}) (Connell 1978; Gunatilleke et al. 2006). Higher tree species diversity in valleys than nearby ridges have also been reported for lowland dipterocarp forests in Sumatra (Rennolls and Laumonier 2000) and Sabah (Nilus 2003).

13.4.2 Species Distributions of Economic Concern

Over 30 years of permanent plot records in stands representing all three associations have allowed us to record changes in species composition and growth from logged vs. unlogged stands (De Zoysa et al. 1991; Gunatilleke and Gunatilleke 1981, 1983, 1985; Ashton et al. 2001a).

13.4.2.1 Valley Association

Canopy dominant timber trees of the valley association comprise *D. hispidus*, *S. megistophylla*, and *S. stipularis* (used for framing, heavy construction, decking) (Ashton et al. 1997a, b). Other large canopy nondominant timber trees include *Mangifera zeylanica* and *Bhesa ceylanica*.

During mast years, the seeds of *S. megistophylla* provide an important source of flour that is made into a sweetened cake (halapa) by villagers. *S. stipularis* provides

resins for temple incense and *M. zeylanica* provide an edible fruit (Ceylon mango) (Ashton et al. 1997a, b). The fruit of a subcanopy nondominant tree, *Garcinia morella*, (Goraka), is used as a spice in fish curries. In large tree fall areas, *M. peltata* (kenda) grows quickly because of the high light and freely available soil moisture – the wood is used in light construction and the leaves in wrappings (Ashton et al. 1997a, b). In addition, within disturbed areas, fast-growing vines *Coscinium fenestratum* (wenewal getta) and *Calamus zeylanicus* (rattan) are used as a medicinal and for craftwork/furniture, respectively. The stem of the medicinal is harvested and its juices used as an antiseptic to treat wounds, or it can be taken as a boiled potion for fevers and colds (Ashton et al. 2001b).

The most important function of this floristic association is riparian protection given that almost all valley sites have fast-flowing water that floods during the SW monsoon. These upper stream and river systems are the main sources of water for downstream agriculture (rice) and drinking water for almost 1/3 of Sri Lanka's population.

13.4.2.2 Midslope Association

The *S. trapezifolia*–*S. rubicundum* association of mid slopes is the most commercially productive zone, mainly because of the high proportion of light-hardwoods (De Rosayro 1942; Merrit and Ranatunga 1959). The midslope association can be considered the most management productive zone because of a mix of relatively fast and slow-growing timber trees, an abundance of nontimber forest products (NTFP) of high commercial value, with soils that are logistically workable, away from sensitive riparian and wetland areas and the steeper slopes of ridges. It is intermediate in site productivity (as measured by tree growth rate) between ridge (less productive) and valley sites (more productive) (Gunatilleke et al. 2006). In mature stands, nearly 90% of the merchantable volume is in the fast-growing light-hardwood species of the canopy (mostly *S. trapezifolia*). Light-hardwoods are not represented as smaller trees below-canopy unless as advance regeneration in the forest understory. Mature stands of this type have standing merchantable volumes of 60 m^3 ha^{-1} (Ashton et al. 2001a). Heavy hardwoods are the slower growing, more valuable timber species,[1] but they represent only about 10% of the merchantable volume. The most valuable timber is a canopy nondominant, *Diospyros quaesita* (a variegated ebony prized for its streaked black and yellow wood for traditional furniture), which is rare and must be supplemented by enrichment planting if desired in the new stand.

Species that provide NTFP on mid slopes increase in abundance after logging in this forest type. *C. zeylanicus* (rattan) increases in stem density from two stems ha^{-1} to over ten stems ha^{-1} after diameter-limit cutting, with stem growth rates that are 1>m $year^{-1}$ (Gamage 1998; Ashton et al. 2001b). Similarly, *Elettaria*

[1]Heavy-hardwoods comprise the slower-growing, more shade-tolerant tree species with denser wood than the light-hardwoods.

cardomomum var. *major* (wild cardamom) regenerates well in disturbed patches, by originating from the soil seed bank (Singhakumara et al. 2000). *Caryota urens* (fishtail palm), tapped for sugar by villagers, is found within the mature forest at very low densities of less than one mature individual ha^{-1} (Gunatilleke and Gunatilleke 1981, 1983; Ratnayake et al. 1988; Ashton et al. 2001b). Poor seed dispersal and sensitivity to predation make *C. urens* difficult to regenerate through natural recruitment, but after seedling establishment it can grow well in high light environments (Ratnayake et al. 1988).

13.4.2.3 Ridge Association

At the other end of the continuum, the ridge association has dense, shorter stature stands with relatively small crowns, and uniform canopies of site-restricted timber trees such as *M. nagassarium* and *S. worthingtonii*. Both are slow growing heavy hardwoods, highly prized for their timbers in temple construction and high-end house construction. Leaves that are used as roofing thatch are harvested from *A. intramarginalis* (behru), an abundant understory shrub (Ashton et al. 1997a, b, unpublished data).

13.5 Silviculture

Important groundwork on the silviculture of mixed dipterocarp forests (MDF) of South Asia started in the 1900s in the Sinharaja region of Sri Lanka (Holmes 1957), the Western Ghats of India (Troup 1921; Kadambi 1954), and the Andamans of India (Chengappa 1944). Taken together, and given the varied regional and topographic differences in shade tolerance among floristic association, all this work argued for different kinds of shelterwood techniques as the most ecologically compatible and economically viable way to regenerate these forests.

For the hill dipterocarp forest of Sri Lanka, our work suggests the same overall approach – the use of shelterwoods. But they are site specific, with the amount of parent tree and residual overstory that are left after regeneration establishment increasing to serve as an increased source of seed and shade on progressing upslope. Greatest retention is therefore on the ridges that comprise the most shade tolerant canopy tree species (*S. worthingtonii*–*M. nagassarium*).

13.5.1 Silviculture for the Ridge Association

On the ridges such a system would resemble the work done by Chengappa (1944) in the Andaman Islands. The best silvicultural term to define this method would be a

"cyclical irregular shelterwood." To initiate the process, the subcanopy is first removed to increase understory light regimes and to release the growth of advance regeneration of the canopy tree species. Sprouting species of NTFP such as *A. intramarginalis* need no other treatment other than periodic harvest of leaves as an NTFP. Other species of NTFP or timber tree species that are density dependent with widely scattered dispersal need to be enrichment planted at this time. Care must be given to judiciously control the sprout growth of the understory and subcanopy species. After a 10-year-period about half the basal area of the canopy is removed leaving the rest to close canopy before another 50% canopy removal 30 years onward to allow the original regeneration, now pole size class, to attain the canopy (Ashton and Peters 1999). The process is repeated at year 60, and again at year 90 such that three cohorts (age-classes) of canopy trees ascend through the strata at any one time (Ashton et al. 1993; Fig. 13.4a). Based on growth data the canopy trees that move through these entries would be harvested at approximately 90–100 years of age with a dbh of 40–50 cm. Compared to the valley and mid slope sites a relatively higher basal area and stem density can be carried within the prescriptions at all times.

13.5.2 Silviculture for Valley Association

On valley sites, the canopy tree association is much more shade intolerant and a more heavy-handed approach can be taken that resembles a one-cut shelterwood (Ashton and Peters 1999; Ashton 2003). Trees left behind are designed to not be removed until the next regeneration entry. Enrichment planting of NTFP and liberation treatments follow establishment of the pioneers of initiation and stem exclusion that quickly form an umbrella canopy of light shade after a single entry cutting that removes the overstory. Release work of advance regeneration and plantings will be important for the first 10 years before leaving completely alone. No other major intrusions should be done until the start of the next rotation at about 50–60 years. It is a relatively simple system but the harvest of early (*M. peltata*, *A. scholaris*, *C. fenestratum*, *Calamus zeylanica* at 10–20 years) and mid seral (*G. morella* at 25-onwards) NTFP should be important economic additions to the management of the stand for timber (Ashton et al. 1993; Fig. 13.4b).

13.5.3 The Midslope Association: A More Detailed Silvicultural and Economic Analysis

Under shelterwood treatments on the midslope association less than a quarter of the basal area remains after logging (<12 m^2 ha^{-1}) usually comprising overstory canopy reserves of *S. trapezifolia*. Basal area rapidly increases to 20 m^2 ha^{-1}

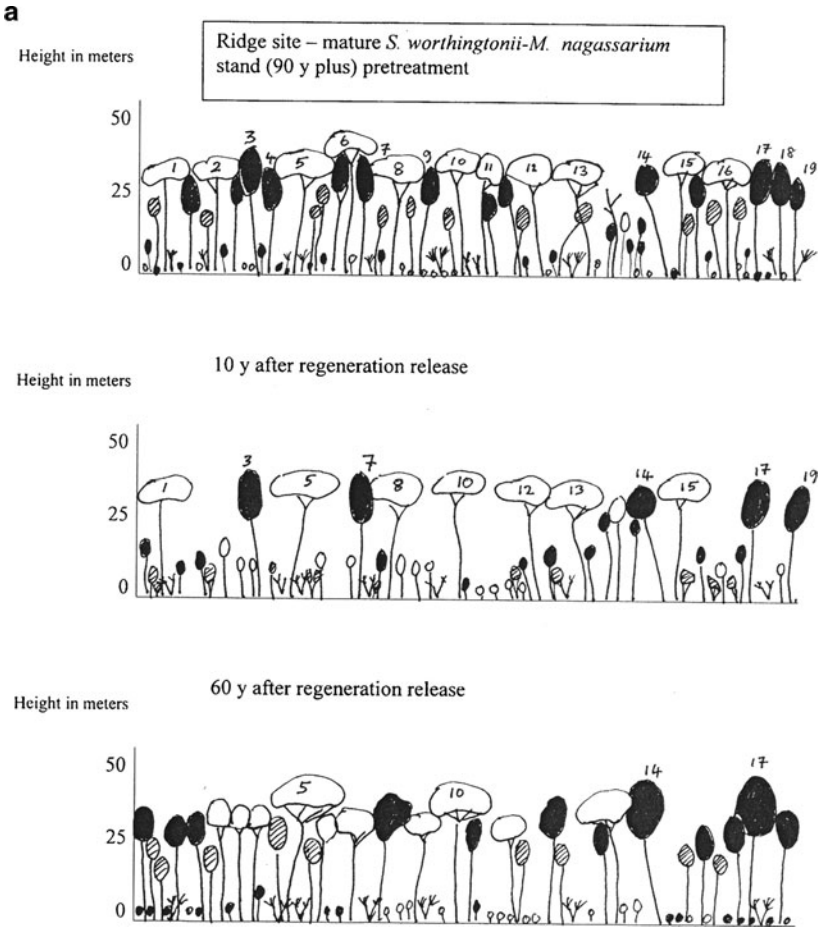

Fig. 13.4 (**a**) Profile A depicts the stylized and simplified condition of a ridge site stand prior to regeneration treatment, with *S. worthingtonii–Mesua nagassarium* trees in the canopy (represented by *open* and *darkened crowns* respectively), and their advance regeneration in the groundstory as saplings and seedlings. Subcanopy trees are represented by slanted stripes, and understory trees and shrubs by frond-like hands. Profile B depicts the stand after the subcanopy has been removed, to release growth of advance regeneration. Other species that are density dependent have been enrichment planted. Judicious control of sprout growth of the understory and subcanopy species has been completed and about half the basal area of the forest canopy has been removed. Profile C depicts the stand after two more entries each removing 50% of the canopy. Three age-classes are now present of canopy dominant trees *S worthingtoni* and *M. nagassarium* – the original canopy trees prior to start of treatments (illustrated by numbers 5, 10, 14, 17); the original regeneration that has now grown and considered 60-year-old canopy trees; and their advance regeneration waiting for the next partial canopy removal at year 90. (**b**) Profile A depicts the stylized and simplified condition of a valley site stand prior to regeneration treatment with *S. megistophylla* and *D. hispidus* trees in the canopy (represented by *open and dashed canopies*). Subcanopy trees are represented by slanted stripes and understory trees and shrubs have darken crowns. Profile B depicts the stand structure and composition10 years after overstory removal with reserve trees (1, 2, 3) judiciously left behind because of ecological or economic value and can be removed only at

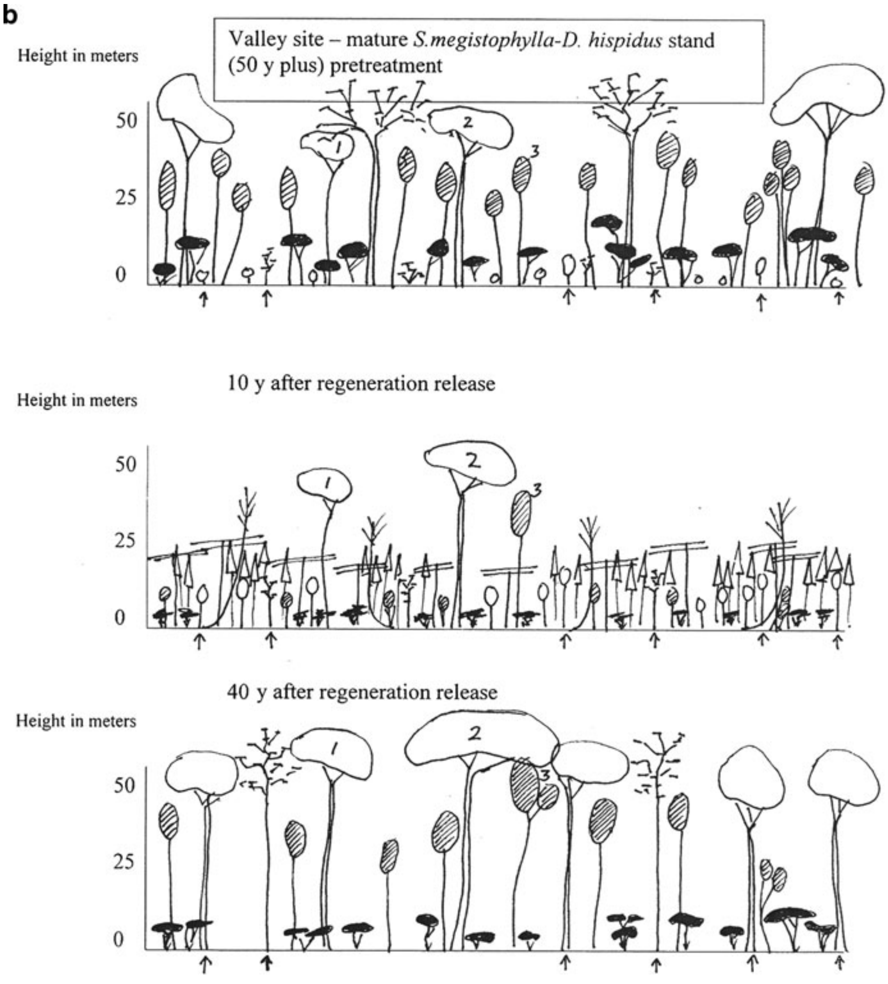

Fig. 13.4 (continued) the next regeneration entry in 50–60 years time. NTFP's (depicted by the fronds of *Calamus zeylanica* supported by the pioneers) and density dependent timber trees have been enrichment planted with follow up cleaning treatments of planted and natural regeneration beneath pioneers of initiation (depicted by *horizontal lines*) and stem exclusion (depicted by *triangles*). Profile C depicts an essentially even-aged, mixed stratified stand after 40 years of growth and development (with a few older reserves). No major intrusions have been done other than to harvest the early successional NTFP's (*Coscinium fenestratum*, *C. zeylanica* at 10–20 years), and mid seral fruits of NTFP's from subcanopy trees (*Garcinia morella* at 25 years and onwards). The pioneers have either been harvested or died from being over topped by the current canopy of 40-year-old (plus) *S. megistophylla* and *Dipterocarpus hispidus*. Subcanopy and understory trees of the same age but largely of vegetative origin fill out the strata. Understory reinitiation of advance regeneration of the canopy tree has not yet started

(1,600 stems ha^{-1}>2 cm dbh) after 10 years regrowth and 25 m^2 ha^{-1} (1,260 stems ha^{-1}>2 cm dbh) after 20 years (see Ashton et al. 1993, 2001a; Ashton and Peters 1999; Ashton 2003). During early stand regrowth, mortality from self-thinning is 1.9% year^{-1}.

Stocking on such sites is good with advance regeneration of canopy timber species normally occupying the groundstory (<1 m) in numbers ranging from 100,000 to 200,000 stems ha^{-1} (De Zoysa et al. 1991). Seldom do seedlings of *S. trapezifolia* and *S. rubicundum* species survive longer than 3 years (Ashton et al. 1995), unless released by the creation of a canopy opening. New cohorts supplement regeneration annually (Dayanandan et al. 1990).

Supplemental enrichment plantings of *D. quaesita*, *C. urens*, *Elletaria ensal*, and *C. zeylanica* can be done using containerized stock. *D. quaesita* should be planted together in groups of three since investigations have shown nearly 50% mortality after planting, and therefore group plantings are more desirable to insure full enrichment stocking. At least two cleanings are required at 3 and 6 years after planting. We estimate that at the rotation end merchantable volumes of *Diospyros* will amount to 10 m^3 ha^{-1}.

Planting of *C. urens* at 25 m spacing is an alternative that could also supplement natural regeneration. The palm is susceptible to porcupine damage and a foliar fungus, both of which have been recorded to significantly affect survival (Gamage 1998). Cleanings around the planted palm need to be done once established. However, the palm can grow well in partial openings, and matures within 15 years providing an inflorescence for tapping once a year for the next 10 years (Ratnayake et al. 1988; De Zoysa et al. 1991). Flowers can be tapped on average for 30 days yielding 3.0 kg of sugar day^{-1} tree^{-1} (Ashton et al. 2001b).

E. cardomomum var. *major*, the native cardamom, can yield over 100 fruit year^{-1} 3 years after planting (Gamage 1998; Gamage et al. unpublished data). However, the shrubs require yearly cleaning and an open environment providing periods of direct sun for best yields. This limits suitable planting sites to skid trails and landings (not more than 10% of the stand area in a well-planned timber harvest). Plants can only productively exist until canopy closure over skid trails. This occurs by year 8 in shelterwoods (De Zoysa et al. 1991; Gunatilleke et al. unpublished data). For shelterwood systems, the productive cultivation period is estimated to be a 5-year-period at the beginning of a 60 years rotation (Ashton et al. 2001b).

C. zeylanicus (rattan, cane) is a climbing palm that can grow more than a meter in a year, reaching lengths of over 20 m in 15 years after planting (Gamage 1998, unpublished data). Cane requires open conditions and a young regenerating forest stand for its best growth. It survives well after planting but its reliance for support on young timber saplings can affect their form. Judicious spacing is important.

In forest stands with extensive regeneration, the most economical silvicultural technique is to use a one-cut shelterwood harvest (leaving single and group reserves for other ecological and structural values) supplemented with enrichment plantings.

At a 4% interest rate, we estimate that these forest stands are worth about \$23,000 ha^{-1}. In forest stands without regeneration, the most economical approach is to use uniform shelterwood with single tree reserves and enrichment plantings (Ashton et al. 2001b). These forests are worth about \$20,000. This compares very favorably to the routine timber-only diameter-limit cuttings (30 year entry cycles) that are widely practised across MDF in Asia, which in our case earns a mere \$7,000. The combination of cultivating NTFP and timber combined can be comparable to tea plantations that are worth about \$26,000 ha^{-1} (Ashton et al. 2001b; Table 13.1). Given other important services that forests provide such as carbon sequestration and watershed protection, and the negative environmental values of tea cultivation (soil erosion, poor drinking water quality, pesticides, loss of biodiversity), the value difference between tea cultivation and sustainable forest management would place clear advantage with the forest management options we have described, when compared with tea (Ashton et al. 2001b; see Table 13.1).

Table 13.1 Net present values (NPV) of silvicultural regimes that (1) rely entirely on natural regeneration; (2) enrich with planting NTFPs and timber; and (3) that include ecosystem services

Regime/landuse	Diameter-limit cutting interest rate		Shelterwood treatments		Tea cultivation	
1. *Natural regeneration ONLY*	4%	6%	4%	6%	4%	6%
Initial timber values	6,097	6,097	7,525	7,525	8,000	8,000
All future timber	434	254	1,293	398	– –	– –
NTFP's with no enrichment	842	858	1,165	820	– –	– –
Total	7,173	7,009	9,983	8,743	– –	– –
2. *With enrichment of Timber/NTFP's*						
Fishtail palm	5,853	4,293	11,013	7,768	– –	– –
Cardamom	609	509	1,148	1,062	– –	– –
Rattan	161	101	128	87	– –	– –
Calamander	768	232	768	232	– –	– –
Intensive tea cultivation	– –	– –	– –	– –	17,735	14,937
Total	14,564	12,144	23,040	17,892	25,735	22,937
3. *With service values*						
Water quality and regulation[a]	6,532	5,234	7,653	6,738	−4,652	−3,298
Carbon credits	+ +	+ +	+	+	–	–
Biodiversity conservation	+	+	+	+	–	–
Recreation/open space	+	+	+	+	–	–
Total stacked value	21,096	17,378	30,693	24,830	21,083	13,839

[a] Forest provides strong regulatory and filter control over surface water runoff as compared tea cultivation which has poor control of surface runoff, high nutrient leachate (often from over fertilization) and sediment loss, and high amounts of pesticide contaminants in the water

The financial analysis has been done for a midslope association in a mature mixed-dipterocarp forest comparing the usual management protocol of diameter-limit cutting with the ecologically based shelterwood regeneration method. The clearance of the forest and replacement by intensive tea cultivation is compared as the alternative land use (NPV in \$USD ha^{-1}; + positive value; − negative value; ++ strongly positive value; −− strongly negative value) (modified after Ashton et al. 2001b)

13.6 Concluding Remarks About Future Directions

Sophisticated techniques to manage multiple forest products were once employed in precolonial systems for various NTFPs garnered from the forest. Products such as early-seral spices and medicinal herbs (e.g., cardamom), vines (e.g., rattan), sugar palm, and other fruit trees (e.g., durian, mangosteen) can be harvested as they mature sequentially within the growing structure of the dipterocarp forest over the course of its rotation (Ashton 2003). Such compatibility makes these systems both ecologically and economically more viable than selection systems based on diameter-limit cutting (Appanah and Weinland 1990; Ashton et al. 2001b).

In addition, the level and sophistication of stand-level delineation and prescription have yet to be incorporated into management that takes into account the unique attributes of the floristic association, topographic relief, soils and hydrology that makes silvicultural treatments stand specific. All too often for ease of management, careful integrated spatial and temporal planning that allows for judicious allocation of stands for different use values is absent. Use values such as protection (services – ecological or hydrological sensitivity) or production (timber and nontimber products) need to be carefully partitioned into dominating uses within the forest landscape. Current technologies in GIS, remote sensing, and landscape management system (LMS) models allow for this, but are seldom used in anything other than a rudimentary way.

Lastly, the majority of the remaining MDF are currently in various states of degradation making their management a large challenge before any degree of sustainability can be achieved (Ashton et al. 2001a). Most also now need rest, and in some cases substantial treatment to enrich and restore some semblance of forest structure and species composition (Adjers et al. 1995; Kuusipalo et al. 1995; Ashton et al. 1997a, b, 1998), which can provide "tomorrow's" new products and services for the citizens of the region. Since most of the remaining forests are restricted to uplands, they therefore potentially have critical future roles as surface watershed protection for downstream drinking water supplies and agricultural irrigation; and for carbon sequestration and global and regional climate stabilization. These are two growing service values that society is now recognizing as irreplaceable.

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